

# PATENT SPECIFICATION

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## (54) MIXING APPARATUS

(71) We, STERLING EXTRUDER CORPORATION, a corporation organized and existing under the laws of the State of New Jersey, United States of America, of 901 Durham Avenue, South Plainfield, State of New Jersey, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to a mixing apparatus suited for mixing plastic materials. Examples of prior art mixing apparatus are found in U.S. Patents 2,910,726, 3,102,716 and Re 26,147.

The machines disclosed in these patents generally include a stator and cooperating rotor both of which are helically threaded for passing material from one end of the apparatus to the other and for subjecting the material to various types of mixing and blending operations during its passage through the apparatus.

In conventional mixing apparatus such as described in the above-mentioned patents, a distinction is made between extensive mixing of the material or materials and intensive mixing. Extensive mixing generally includes the dispersal of materials into a homogeneous mixture while intensive mixing is more directed to a shear working of mixed materials. Where extensive mixing is desired, an apparatus such as disclosed in the above-mentioned patent 3,102,716 is employed. To create this extensive mixing, the lands of the threaded rotor and stator are generally minimum in size so that there is a minimum of closely spaced surfaces on the rotor and stator passing each other during rotation of the rotor. A construction of the type shown in patent 3,102,716 produces maximum mixing of the materials while maintaining a minimum shearing of the materials.

Where it is desired to subject the material to intensive mixing, an apparatus such as shown in U.S. Patent 3,164,375 is employed.

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Here, the lands of the cooperating rotor and stator are relatively wide and positioned with a close clearance so as to create shearing of the material as it is passed therebetween. Depending on the material being mixed and the results desired, either an extensive mixing or intensive mixing apparatus will be used.

With the machines disclosed in the above-mentioned patents such characteristics as the construction of the threaded surfaces and temperature and speed restrictions limit the materials which may be mixed therein. These machines are not, for example, well suited for mixing plastic materials including many polymeric materials where it is desired to improve their molecular weight distribution. Machines of the types described above are generally unsuited for this purpose because they cannot mix the polymeric materials with a progressively stepless increase in shear rate up to a predetermined maximum which can be varied.

In addition to the above-described extensive and intensive mixing machines, prior art machines for handling polymeric materials have included single and twin screw extruders, batch and continuous internal mixers and milling machines. Various ones and combinations of these machines have been used for particular processing operations; but they have not been completely satisfactory because of either cost of the installation, operation and maintenance, room required for the machine layout and/or inherent processing limitations. For example, in making master-batches or color concentrates, prior techniques have generally employed batch or continuous internal mixers in conjunction with a mill or extruder. Alternatively, either twin screw extruder or mill has been used by itself. These prior art techniques are not completely satisfactory in that they either result in high capital investment for the required process line, require a number of separate pieces of equipment and large floor space and/or give rise to high labor and maintenance costs. Also when it is desired to change from one processing operation involv-

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ing certain materials to a different operation, it is generally necessary to use different machine layouts or change extruder screw configurations.

5 Prior art techniques have also presented difficulties in compounding and extruding certain polymeric materials and required specially built single or twin screw extruders. Conventional twin screw extruders can  
10 generally handle a greater number of extrusion and compounding operations and also a greater variety of let down or diluting operations than can single screw extruders. With twin screw extruders, however, the cost is  
15 much greater and if the resin is changed the twin screws have to be changed or in some cases rebuilt by assembling components in different combinations. This not only requires stockpiling of different screw components but  
20 also necessitates extended shut down periods when a change-over is made. Even with specially built screw extruders there are still certain difficult extrusions, compounding and let down operations that cannot be done  
25 economically or in the pounds per hour desired.

Also, prior art machines presently available for compounding and extruding shear and heat sensitive materials are not completely satisfactory. This is because these machines do  
30 not have the capability of controlling the shear rates and temperatures to which the material is subjected during the processing operation. Accordingly, special precautions must be taken to prevent degradation, premature reaction or  
35 the occurrence of some other undesired physical or chemical change. In the past, processing of these materials has required the use of continuous fluxing mixers followed by a hot melt extruder or mill for transforming the  
40 product into pellet or dice form. Alternatively specialized extruder screw configurations have been required.

The present invention relates to an apparatus for mixing plastic materials which does not  
45 have the operating limitations present in prior mixing apparatus. The apparatus of the present invention advantageously may be used for carrying out the method of mixing described and claimed in Co-pending Application No.  
50 44992/73 (Serial No. 1354147).

The present invention provides a mixing apparatus having an outer screw member and a co-operating relatively rotatable inner screw member disposed within said outer screw member, a material charging end and an exit end,  
55 wherein: said inner and outer screw members each have an extensive mixing section extending from the charging end of the machine toward the exit end thereof with at least one helical thread defined by land and adjacent  
60 groove convolutions, (1) said lands being narrower than the grooves with the lands of said inner screw member defining a first envelope and the lands of said outer screw member defining a second envelope disposed in

radially opposite co-operating alignment with said first envelope, (2) the depth of opposite grooves in the inner and outer screw members varying at least once, one from a minimum to a maximum and the other from a maximum to a minimum along at least a portion of said extensive mixing section, to pass the material from one member to the other as it is fed axially through said machine, and (3) the cumulative depth of the opposite grooves being progressively smaller at locations nearer the exit and of the machine along said portion of the extensive mixing section. In a preferred embodiment of the present invention, two separate mixing sections are provided along the length of the apparatus, one for extensively mixing the material and the other for intensively mixing it. The first extensive mixing section extends from the charging end of the apparatus toward its exit end. In this section, the opposed lands on the rotor and stator are relatively narrow to produce the desired extensive mixing. In addition, the cumulative groove depth between opposite grooves in the rotor and stator is made progressively smaller at locations nearer the exit end of the apparatus. Also, in this section, the characteristics of the threading of both the rotor and stator, as for example the pitch, pitch angle and number of flights, are chosen to produce the desired mixing of the particular materials being fed through the apparatus.

Disposed downstream of the extensive mixing section is the intensive mixing section. Here, the lands of the oppositely disposed stator and rotor are relatively wide and closely spaced to effect shearing of the material passing therebetween. In the intensive mixing section of the apparatus, the rotor and stator are conically tapered so that adjustment in the shear rate to which the material is subjected can be varied as dictated by the particular material being mixed.

Although the interface between the rotor and stator in the intensive mixing section is conically tapered, the interface between the lands of the rotor and stator in the extensive mixing section defines a cylinder. With this construction axial adjustment of the rotor may be made to vary the shear rate to which the material is subjected in the intensive mixing section and such adjustment will have a negligible effect on the mixing operation in the extensive mixing section.

By adjusting the axial position of the rotor relative to the stator and by varying the running speed of the machine, the plastic materials may be subjected to shear rates at the exit end of the machine ranging anywhere from 50 to 5000 reciprocal seconds or even below and above these values with certain materials. Also, with the conical and cylindrical interfaces and the continuously decreasing cumulative groove depth in the extensive mixing section, the apparatus, in

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effect, becomes a stepless extensive-intensive mixer with a variable shear rate cutoff at the exit end where the material is extruded through a die.

5 With the apparatus of the present invention, many different polymeric materials may be mixed, compounded and extruded by simply adjusting the operating conditions of the machine and without requiring multiple machines or different screw configurations of the rotor and stator.

10 Also, the apparatus of the present invention may be used to improve both the visual and structural properties of many polymeric materials by making the molecular weight distribution more uniform. More particularly, the extensive mixing of the plastic materials immediately preceding the final intensive mixing may be controlled by choosing appropriate land and groove configurations and by controlling the heat transfer to and from the material to properly prepare the material for its final passage through the intensive mixing section. With such preparation of the material and final mixing at high shear rates, the material exiting from the apparatus will have the desired uniform molecular weight distribution.

15 With the present invention, it is possible, for example, to reduce the gel content in low density polymer films so as to produce clear films and thus avoid the creation of unacceptable fish eyes. The apparatus of the present invention may also be used for improving other structural properties of polymeric materials, such as those containing long entwined polymer chains or crystallized resins. The stepless mixing can be used to effect a breaking of the polymer chains and the reduction of the crystallinity of the resins. An embodiment of the present invention is described with reference to the accompanying drawings, in which:—

20 Fig. 1a is a schematic view in cross section of the charging end of the apparatus showing part of the extensive mixing section; and

25 Fig. 1b is a schematic view in cross section of the exit end of the machine showing the remainder of the extensive mixing section and intensive mixing section thereof.

30 In the drawings, the mixing apparatus is shown as comprising an inner screw member 1 in the form of a rotor and an outer screw member 2 forming a stator. The rotor is mounted for rotating within the stator, the drive for this being from the motor 3. The rotor is also mounted for axial adjustment within the stator by means of a structure generally shown at 4.

35 Fig. 1a shows the charging end of the apparatus. Here, material to be mixed is fed through an inlet 5 in the stator. The feeding is by gravity from the metering mechanisms 6 and 7. One metering mechanism may, for example, feed a resin while the other feeds a

40 pigment or filler to be mixed with the resin. As the material to be mixed is passed through the charging end, it is fed along the axis of the machine under the influence of the cooperating helical threads 8 and 9 formed on the rotor and stator members. After the material has been subjected to the desired mixing and working operations as more fully described below, it passes out the exit end of the apparatus. Here, a suitable die 10 having an extrusion orifice is provided.

45 The apparatus is constructed with both an extensive mixing section and an intensive mixing section. With reference to the drawings, the extensive mixing section extends from the charging end of the apparatus toward the exit end and is divided into six mixing stages designated I—VI. The intensive mixing section, on the other hand, is disposed downstream of the extensive mixing section at the exit end of the machine and can be constructed with one or more stages. In Fig. 1b, the intensive mixing section is designated at 11.

50 In addition to the above structure, the presently preferred construction of the apparatus includes a venting section disposed intermediate the ends of the extensive mixing section. The venting section includes a vacuum pump 12 for facilitating removal of gases, water and other volatiles from the material. If desired, a number of separate venting sections may be provided for increasing the quantity of gases, water and other volatiles withdrawn from the material. The apparatus also includes zoned heaters and cooling coils designated, respectively, at 14 and 15 disposed along the length of the stator structure for controlling the temperature of the material being fed through the apparatus. For cooperating with the heaters and cooling coils, the rotor is cored at 13 for passage of cooling water.

55 Completing the description of the basic structure of the apparatus, the stator 2 is constructed from a number of axial segments. These segments correspond in length to the length of the various Stages I—VI of the extensive mixing section and to the length of the stages in the intensive mixing section. This construction facilitates the different internal threading thereof as more fully described below.

60 In accordance with the teachings of the present invention, the helical threading of the rotor and stator in the extensive mixing sections is defined by land and adjacent groove convolutions with the lands being narrower than the grooves. Preferably, the lands are as narrow as structurally possible so that the opposing surfaces defined thereby will be at a minimum. In addition, the lands on both members are formed to lie in concentric cylindrical surfaces and produce a cylindrical interface designated by the dashed line 17.

65 Each stage of the extensive mixing section

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5 advantageously has a certain helical thread arrangement depending on the mixing operation to be performed. Also, the threading of the rotor and stator at the charging end and in the venting section of the apparatus is constructed for cooperating with the other threaded sections to effect the desired mixing and working of the material being fed through the apparatus.

10 Referring to Fig. 1a, the rotor at the charging end of the apparatus is shown as being deeply grooved while the inner surface of the surrounding stator is smooth surfaced. Advantageously, the groove depth of the rotor at the charging end of the apparatus is at a maximum so as to permit introduction of a wide range of materials without requiring a hopper stuffer. Also, with the rotor thread at the charging end having the helix angle shown in Fig. 1a, the introduction of a maximum amount of material is facilitated. In construction, the pitch of the rotor thread at the charging end of the apparatus is advantageously one diameter of the rotor and the threading is of the single start configuration (this is represented only schematically in the drawings). With this construction, plastic granules or powder, pigment or fillers in proportions up to 50 per cent by weight, and in some cases even higher, can be metered separately into the charging end of the apparatus or added as a pre-blend.

30 After the material is dropped into the charging end of the apparatus, it is fed along the rotor to the extensive mixing section of the apparatus and through the various Stages I—VI thereof. As shown in the drawings, the first four stages are located upstream of the venting section while the next two stages are downstream thereof. In the upstream stages, the extensive mixing generally produces a melting and mixing of the material and the wetting out of any additives. In the downstream stages, the material is subjected to further mixing to properly prepare it for intensive mixing in section 11.

35 In Stage I of the extensive mixing section, the rotor and stator are constructed to readily accept the material from the deep grooves at the charging end and to start extensive mixing, melting and encapsulating of any pigment or fillers. More particularly, the grooves of the rotor and stator are constructed so as to pass the material from the rotor to the stator. For this purpose, the groove depth in the rotor is decreased from a maximum to a minimum while the depth of the opposite groove of the stator is increased from a minimum to a maximum. Also, the rotor in Stage I is provided with a second flight of threads of the same pitch as the thread in the charging end of the apparatus while the stator has a two start thread configuration; (again, this is shown only schematically in the drawings). Finally, the cumulative groove depth of the rotor and stator is made progressively smaller at locations

nearer the exit end of the apparatus. The decreasing nature of the cumulative groove depth in Stage I is shown by the non-parallel relationship of the extended lines 18 and 19 drawn tangent to bottom surfaces of the grooves in the rotor and stator.

After passing through Stage I, the material enters Stage II where it is transferred back from the stator to the rotor. For this purpose, the stator is provided with grooves of decreasing depth while the rotor is provided with grooves of increasing depth. Also, for providing a more intensive working of the material in Stage II, the helix angle of the rotor is decreased and a one or two start threaded configuration is used while the stator retains its two start threaded configuration. As in Stage I, the cumulative groove depth of the rotor and stator in Stage II progressively decreases.

85 In Stage III the material is once again passed from the rotor to the stator, the groove depth of the rotor varying from a maximum to a minimum and that of the stator from a minimum to a maximum. In Stage III, the rotor continues with the threads having the same helix angle as provided in Stage II. The stator, on the other hand, changes from a two start to a one start configuration to increase the intensity of the mixing. As with the previous stages, the cumulative groove depth again decreases to further intensify the mixing action on a gradient scale.

100 In Stage IV, the material, is once again, passed back from the stator to the rotor by using the appropriate groove configurations while the decreasing of the cumulative groove depth is continued for further intensifying of the mixing of the material. In Stage IV, the helix angle in the stator remains the same as it was in Stage III. In the rotor, however, the helix angle is increased for optimum transport of the material and proper feeding into the venting section.

The particular configuration of the threading of the rotor and stator in Stages I—IV may be changed for different materials and for producing different mixing operations. In each case, however, the interface formed by the lands of the rotor and stator will lie along a cylindrical surface and the cumulative groove depth will progressively diminish at locations nearer the exit end of the apparatus. For example, after the material has been melted and any pigment or fillers have been encapsulated in Stages I and II, the intensity of the mix may be increased or decreased, as desired, by changing the configuration of the cooperating threads in Stage III and IV so as to produce a relatively homogenous mix and assure that the additives become completely wetted out.

After the material passes through Stage IV, it may be subjected to venting depending on whether it is desired to remove any entrapped air, moisture or other volatiles. The venting

may be directly to atmosphere or may be effected by the vacuum pump 12. Where a venting section is used, the groove depth of the rotor in this section is advantageously at a maximum commensurate with proper mixing in the stages on either side. By employing a venting section in the apparatus, not only is the air and moisture removed; but in addition, the mixing of the material downstream of the venting section is improved. This is so since the removal of the air and moisture allows the shear work produced downstream of the venting section to be transmitted directly to the pigment, fillers and any agglomerates in the material without the cushioning effects which trapped air, moisture and other volatiles would tend to create.

In Stage V, the groove depth of the rotor at the end immediately adjacent the venting section is the same as the groove depth of the rotor in the venting section. This groove depth, however, progressively varies from a maximum to a minimum toward the downstream end of Stage V while the depth of the opposite grooves of the stator varies inversely from a minimum to a maximum. As with the preceding stages of the extensive mixing section, the cumulative groove depth of the rotor and stator progressively diminishes in Stage V. The groove depth in the stator at the downstream end of Stage V is dictated by the maximum shear work and pumping efficiency desired. The shallower the cumulative groove depth at the downstream side of Stage V, the higher the pumping efficiency attained. An increase in pumping efficiency is desired preparatory to feeding of the material into the intensive mixing section of the apparatus.

After the material passes through Stage V, it is fed into the final Stage VI of the extensive mixing section of the apparatus. Here, the grooves of the rotor and stator are configured to once again pass the material back from the stator to the rotor. Also, the cumulative groove depth in Stage VI progressively diminishes toward the exit end of the apparatus. It is emphasised that in the drawings the stator and rotor grooves in all stages are represented only diagrammatically.

With the intensive mixing section constructed for varying the shear rate between about 50 to 5000 reciprocal seconds, the cumulative groove depth of Stage VI immediately upstream of the intensive mixing section may be of such a value so as to provide a shear rate which is about equal to the lower range of shear rates producible in the intensive mixing section. More particularly, the cumulative groove depth in Stage VI immediately upstream of the intensive mixing section will be equal to or greater than the maximum clearance obtainable between the cooperating surfaces of the rotor and stator in the intensive mixing section. With this construction, the material can be subjected to shear rate

which progressively increases to a value of from about 30 to about 500 reciprocal seconds immediately preceding intensive mixing. Then in the intensive mixing section, the apparatus may be set to subject the material to the final shear rate desired ranging anywhere from about 50 to 5000 reciprocal seconds.

After the material has been fed through all of the six stages of the extensive mixing section, it is fed directly into the intensive mixing section 11. In the intensive mixing section, the threads of the rotor and stator are formed with relatively wide lands and narrow grooves to provide large cooperating surfaces between which the material is to be fed. As shown in Fig. 1b, the lands of the rotor and stator are located on closely spaced, conically tapered surfaces. Also, the groove depth advantageously varies twice between a minimum to a maximum in both the rotor and stator to effect transfer of the material back and forth between the rotor and stator. Instead of the groove construction shown, it may, in some situations, be desirable to provide the intensive mixing section with smooth, conical or otherwise tapered surfaces. In either case, the large cooperating surfaces provided produce a good intensive mixing of the material in the final mixing stage of the apparatus. The material as it leaves the intensive mixing section is advantageously extruded through a suitable die 10 such as used with extruders.

With the cylindrical interface construction in the extensive mixing section and the conically tapered interface in the intensive mixing section, final intensive mixing of the material may be effected at a wide range of shear rates without adversely affecting the mixing in the extensive section. Variation in the mixing of the intensive mixing section is controlled by adjusting the axial position of the rotor relative to the stator. With the presently preferred construction, sufficient relative axial movement is provided for effecting variances in the shear rate generally from 50 to 5000 reciprocal seconds. With certain materials, however, lower or higher shear rates may be produced. The shear rate to which the material is subjected to the intensive mixing section is also controlled by controlling the speed of rotation of the rotor within the stator, with higher speeds increasing the shear rates.

Although changes in the axial clearance of the rotor and stator will have an effect on the intensive mixing section of the apparatus, it will not have any appreciable effect on the mixing in the extensive mixing section due to the cylindrical interface between the rotor and stator in this section and due to the narrow lands. Axial movement will not change the clearance between the rotor and stator in the extensive mixing section. Also, with the construction of the apparatus as described above, the operating speed may be increased with a minimum buildup of temperature in the

material in the extensive mixing section. This is due to the diverging and converging vortices of the material in the grooves of the rotor and stator which bring the bulk flow of the material, layer by layer, in contact with the heat transfer surfaces of the rotor and stator. Thus, good turbulence can be introduced into relatively viscous materials without causing excessive increase in temperature during the extensive mixing.

The zoned heaters and cooling coils in the extensive mixing section can be adjusted to control the heating and cooling of the material being fed through the apparatus. Different materials require different cooling and heating during the various stages of mixing. Of significance here, is the cooling which may be produced in Stages V and VI immediately preceding the intensive mixing section. Cooling of the material at this location will cause an increase in its viscosity which, in turn, will increase the shear work applied to the material. This will cause further homogenization and breakdown of any aggregate in the material such as caused by pigments or fillers and properly prepare the material for its final intensive mixing. At the same time, the shear work is being increased; the progressively decreasing cumulative depth of the groove in Stages V and VI produces the desired increase in the shear rate to the value approaching the low end of the range obtainable in the intensive mixing section. Alternatively, where shear work and/or shear rate is not to be increased, as where breakdown of aggregates or destruction of fibrous fillers is not desired, the threaded configuration of the rotor and stator in Stage V and VI can be changed and the heating or cooling of the material appropriately adjusted to produce the desired results.

With the construction of the apparatus as described above, the material fed into the inlet is taken up by the rotor helix and peeled off in a layer by layer fashion by the stator helix as the groove depth of the rotor decreases and that of the stator increases. As this transfer is occurring, the vortexing action taking place in the material in the rotor grooves becomes smaller while that in the stator becomes larger. Thus, all material on the inside of the vortex is transferred to the outside, and vice versa, as many times as the material is passed between the rotor and stator. This insures that all material in passing through the various stages of mixing comes in close proximity to both the rotor and stator thus permitting good heat transfer between all of the material and the temperature controlled surfaces of the rotor and stator.

With the present invention, a single piece of equipment may be used in the production of various color concentrates and masterbatches. Pigments may be added to resin either in low concentrations of a fraction of a per cent, intermediate concentrations or high con-

centrates. It is only necessary to alter the feeder settings, temperature profiles, running speeds and clearance between the rotor and stator to handle a large variety of polymeric materials. Resins such as ABS, Nylon, low density and high density polyethylene, general purpose or high impact styrene, PVC, polypropylene and polycarbonate can be run in the same machine by simply varying the operating conditions thereof.

In addition, masterbatches or color concentrates pre-dispersed, for example, with carbon black (medium channel black or fine furnace black) or other pigments may be mixed with additional resin in let down operations. No special extruders or combinations of mixers and extruders are required. This is also true with respect to the melting and extruding of materials such as high density linear polyethylene and the melting and compounding of different combinations of resins having different physical properties. With the present invention, the processing of all of these materials may be carried out in the same apparatus; and the amount of shear work to which the material is subjected can be controlled whether the system requires a high shear rate and high temperature treatment or a low shear rate and low temperature treatment.

Controlling the shear work is especially important with resin systems where instead of the shear work increasing with an increasing shear rate, it decreases due to the viscosity going down more rapidly than the shear rate goes up. In such situations, the ability to run the low shear rates with low temperatures is of paramount importance. Thus, by cooling of the molten resin to just above the softening temperature, the shear work can be optimized even at minimum shear rates.

Due to the excellent heat transfer capabilities of the apparatus of the present invention and due to the fact that the intensive mixing may be varied over a wide range of shear rates, it is possible to compound and extrude many shear sensitive materials which in the past required specialized equipment. For example, cross-linkable polyethylene may be made by mixing polyethylene with dicumyl peroxide in the transfer and the shear rate and temperature to which the material is subjected controlled to preclude premature setting.

Also, other shear sensitive material such as precharged, expandable polyethylene pellets can be produced in the apparatus of the present invention while maintaining the material below the set off temperature which would prematurely produce a porous or foam material.

In addition, glass filled polypropylene pellets may be produced with the apparatus and method of the present invention by mixing chopped glass fiber filaments with the polypropylene in either powdered or pellet form.



The glass fibers have to remain intact to impart the desired strength to the finished pellets; and this is possible with the present invention since the shear rates to which the material is subjected can be limited. Another shear sensitive material which may be processed in accordance with the method of the present invention is rigid PVC in either powdered or pellet form. This material can be extruded directly into pipe or sheet form. By controlling the heat transfer and shear rates of the material, degradation is prevented.

The processing of the various polymeric materials as described above is generally done with the material received in a dry, solid state. Typically, the material may be in either granular powder, flake, diced or pellet form. The apparatus of the present invention is also adaptable for mixing and compounding molten polymeric materials with solid and/or liquid additive materials. This is particularly advantageous where the polymeric material which is to be combined with a particular additive is, itself, the output of a prior processing operation.

With the present invention, molten material produced in one processing operation can be fed directly into the mixing apparatus and there combined with other additive materials in either solid or liquid form. For example, molten resins from a reactor may be fed directly to the apparatus of the present invention for the addition of color pigments, antioxidants, flame retardants and so forth. Also, liquid plasticizers, color pigments and other additives can be added and properly mixed with PVC and Nylon without causing decomposition of the material. Similarly, hot melts such as adhesives and coatings used for paper, cardboard and fabrics can be readily compounded in accordance with the method and apparatus of the present invention. An example is the compounding of low density polyethylene with a suitable wax added in either liquid, pellet or granular form.

From the above, it will be seen that a particular advantage of the present invention is that a number of processing operations can be performed on various polymeric materials and that all of these operations can be performed by a single apparatus. Heretofore, these processing operations could only be performed with the specialized equipment and sometimes only at considerable expense.

#### 55 WHAT WE CLAIM IS:—

1. A mixing apparatus having an outer screw member and a cooperating relatively rotatable inner screw member disposed within said outer screw member, a material charging end and an exit end, wherein:

60 said inner and outer screw members each have an extensive mixing section extending from the charging end of the machine

toward the exit end thereof with at least one helical thread defined by land and adjacent groove convolutions, 65

(1) said lands being narrower than the grooves with the lands of said inner screw member defining a first envelope and the lands of said outer screw member defining a second envelope disposed in radially opposite cooperating alignment with said first envelope, 70

(2) the depth of opposite grooves in the inner and outer screw members varying at least once, one from a minimum to a maximum and the other from a maximum to a minimum along at least a portion of said extensive mixing section, to pass the material from one member to the other as it is fed axially through said machine, and 75

(3) the cumulative depth of the opposite grooves being progressively smaller at locations nearer the exit end of the machine along said portion of the extensive mixing section. 80

2. A mixing apparatus according to claim 1 wherein: 85

said inner and outer screw members each have an intensive mixing section at the end of the machine with a major part of the opposite peripheries of said inner and outer screw members defining third and fourth envelopes, respectively, disposed in radially opposite cooperating alignment with each other. 90

3. A mixing apparatus according to claim 2 wherein: 95

(a) said first and second envelopes are cylindrical; and 100

(b) said third and fourth envelopes are tapered.

4. A mixing apparatus according to claim 3 wherein:— 105

said third and fourth envelopes are conically tapered toward the exit end of said machine.

5. A mixing apparatus according to claim 2 wherein: 110

said inner and outer screw members in said intensive mixing section are movable toward and away from each other to vary the clearance between said third and fourth envelopes. 115

6. A mixing apparatus according to claim 4 wherein: 120

said inner and outer screw members are movable axially relative to each other to vary the clearance between said third and fourth envelopes.

7. A mixing apparatus according to claim 6 wherein: 125

the inner and outer screw members in said intensive mixing section each have at least one helical thread defined by land and adjacent groove convolutions; said lands being generally wider than said

grooves and located in said third and fourth envelopes; and  
the depth of opposite grooves in the inner and outer screw members varying, one from a minimum to a maximum and the other from a maximum to a minimum along a least a portion of said intensive mixing section.

8. A mixing apparatus according to Claim 6 wherein:

the opposite groove depths in said extensive mixing section vary a plurality of times between minimum and maximum to pass material at least once from the inner member to the outer member and back to the inner member as it is fed axially of said machine.

9. A mixing apparatus according to claim 6 wherein:

the cumulative groove depth of said inner and outer screw members immediately upstream of said intensive mixing section is equal to or greater than the maximum clearance obtainable between said third and fourth envelopes.

10. A mixing apparatus according to claim 6 wherein:

(a) said third and fourth surfaces are movable relative to each other to vary the shear rates obtainable in the intensive mixing section over a predetermined range and

(b) the cumulative groove depth of said inner and outer screw members immediately upstream of said intensive mixing section is of value providing a shear rate thereat about equal to the shear rate at the lower end of said range.

11. A mixing apparatus according to claim 10 further including:

cooling means disposed immediately upstream of said intensive mixing section for cooling the material to increase its viscosity and the shear work to which it is subjected.

12. A mixing apparatus according to claim 6 wherein:

the extensive mixing section includes a venting section intermediate its ends with the cumulative depth of the grooves of the inner and outer screw members at said

venting station being substantially uniform.

13. A mixing apparatus according to claim 12 wherein:

(a) the outer member at said venting station has a smooth inner surface; and

(b) the grooves in the inner member at said venting section are at a maximum for partial filling with the material being fed through the machine.

14. A mixing apparatus according to claim 12 wherein:

the depth of the opposite grooves in the inner and outer screw members on axially opposite sides of said venting section vary at least once, one from a minimum to a maximum and the other from a maximum to a minimum.

15. A mixing apparatus according to claim 14 wherein:

the opposite groove depths upstream of said venting section vary a plurality of times between minimum and maximum to pass material at least once from the inner member to the outer member and back to the inner member with the material being in said inner member as it is fed axially into said venting section.

16. A mixing apparatus according to claim 15 wherein:

the groove depth of the inner screw member is at a maximum at said venting section and immediately downstream thereof.

17. A mixing apparatus according to claim 15 wherein:

(a) the groove depth of the inner screw member is at a maximum at the charging end of the machine; and

(b) the outer member at the charging end of the machine has a smooth inner surface.

18. A mixing apparatus substantially as hereinbefore described with reference to and as shown in the accompanying drawing.

CRUIKSHANK & FAIRWEATHER,  
Chartered Patent Agents,  
29 St. Vincent Place,  
Glasgow, C.1.  
Agents for the Applicants.

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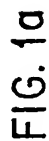


FIG. 1b